Automatic Testing in Telephone Manufacture

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A general discussion is given on the philosophy behind the development of automatic test facilities and the relationship of this activity to product design and manufacturing engineering. A brief historical discussion of early automatic test machines used by the Western Electric Company leads to a summary of design considerations. These considerations are then illustrated by descriptions of the specific techniques used in three automatic facilities of considerable diversity.

INTRODUCTION

Many of the parts used in the telephone plant are made in such numbers that automatic shop testing of them is desirable. The cost of manual testing by suitable personnel is high, and its nature so repetitive and dull that accuracy suffers. Fortunately, in many cases the complexity of the test requirements has matched the state of the art and the business picture well enough to warrant the development of machine methods. It is our purpose in these articles to review the art as it has evolved in the Manufacturing Division of the Western Electric Company, and to describe some of the techniques. This is done with the hope that improvements or extensions to other testing or manufacturing problems may be suggested.

It should be emphasized that the developments treated here and in the other papers[3-9] have required cooperation among testing and manufacturing engineers in the Western and product design engineers in the Bell Telephone Laboratories. Modifications of design for Western's convenience, changed methods for translating basic requirements into manufacturing test requirements, informal Laboratories suggestions of approaches to manufacturing and testing problems, all are commonplace. The boundaries of the specialists' domains are readily crossed.

Testing is a process for proving something such as quality of a prod-

uct or accuracy of a computation. In one form or another, testing is essential in manufacture. It insures against further investment of effort in product found bad. More importantly, it provides information for the manual or automatic correction of earlier processes, to prevent manufacture of additional faulty product. Also, its techniques and devices are used in many applications where testing is not the object. Table I gives a listing of functions, with examples of some of our automatic means, that illustrates this. Of these, 1a, 4, and 5a are testing functions. The remainder are manufacturing processes.

TABLE I

Function	*Example*
1. Sorting, either a. sorting good from bad or	A network testing machine at Indianapolis.[1] A relay coil test set at Kearny.[2]
b. sorting into cells for selective assembly	A capacitor test machine at Hawthorne.[3]
2. Adjusting:	An adjusting machine for flat type resistors at Haverhill.[4]
3. Calibrating:	A calibrating machine for oscillator film scales at Kearny.[5]
4. Plotting data:	Continuous thickness test systems for alpeth and stalpeth cable sheath at Hawthorne and Kearny.[6, 7]
5. Operation of wired equipment, a. to verify accuracy of wiring or fulfillment of purpose, and b. to enable prompt location and correction of faults.	Cardomatic and tape-o-matic test sets for key telephone equipments and wired relay units at Hawthorne and Kearny.[8, 9]

GENERAL

The fundamental steps necessary to any testing operation are:

1. Putting the item to be tested in location;
2. Subjecting the item to a specified set of conditions;
3. Observing the results or the reaction of the item to the conditions;
4. Comparing the observed results to required results;
5. Deciding on the basis of the comparison what disposition to make of the item;
6. Indicating the disposition;
7. Making the disposition. (This may mean transportation, repair or adjustment.)

In purely manual testing all of these steps would be initiated by human

operators. In many cases it is feasible for all steps to be taken automatically. The bulk of our accomplishment in automatic testing, however, has been in steps 2 through 6. We do not ordinarily use "automatic" to describe rudimentary automaticity in combinations among steps 3, 4, and 5.

The present models of many of our machines have evolved from earlier models, either because of changed product or test requirements or through improved designs worked out for plant expansion or cost reduction. The names of engineers associated with the various developments mentioned are included in the references. About 1927 there were put in use at Hawthorne two machines, one for gaging a number of critical dimensions and performing a breakdown test on carbon protector blocks,[10] and the other for heat coils.[11] In the protector block machine the blocks follow a linear course drawn by an indexing chain conveyor through a number of positions where the various checks are performed. Failure of any block at a position causes a jet of air to blow the block into the opening of a chute which conducts it to a reject pan. Good blocks are delivered into a pan at the end of the run. The heat coil machine has an indexing turret over a ring of ports which open selectively to permit good or rejected coils to fall into chutes. The test parameters are three gaged dimensions and dc resistance.

In 1929 a machine with an indexing turret was put in use, testing paper capacitors for dielectric strength and leakage resistance,[12] and sorting them into 13 cells for capacitance grouped around a nominal 1 mf. The 13 cells correspond to 13 segments in a commutator disposed along the scale of a microfarad meter. For a given test capacitor, when the meter needle reaches its deflection a bow depresses it against the nearest segment, establishing a circuit through a relay. A system of relays then locks up and serves as a memory to operate a solenoid later when the turret has brought the capacitor to the point of disposition. Action of the proper solenoid causes the capacitor to be deposited in its cell. The cells are arranged as parallel files in a horizontal plane and, starting with the cells empty, the machine will in effect produce a stovepipe distribution curve. Capacitors from the middle cell and its upper neighbors may be used as 1 mf capacitors, and those from more remote cells combined, large with small, to make 2-mf capacitors.

Also in 1929 a turret type machine was first used for sorting mica laminations.[12] The sorting parameter was ac dielectric strength, the criterion being failure at 1760 volts r.m.s. The individual laminations were carried from position to position by vacuum fingers mounted on a turret. Again locking relays were used, in this case to operate a solenoid controlled

valve in the vacuum line at the right time in the turret indexing cycle to drop the laminations as class "A" or "B" mica.

Experience with these machines and with others that followed brought into being a more or less orderly body of knowledge as to what features are desirable and what constitutes good design in an automatic test machine.

If the machine is to have speed, reliability and long life, attention should be paid to the following matters:

1. *Reduction of the test process time to as low a figure as the capabilities and use of the product will permit.* Thus, if one of the requirements of a capacitor is a maximum limit on its leakage current measured after a charge time of 60 seconds, and if the materials and manufacturing process are such that a unit is surely good or bad after a 25-second charge, then the machine may be designed to charge for, say, 30 seconds. Frequently the only limitation is the speed of the machine itself. When this is true, it must be worked out so as to satisfy the needed production rate. Obviously the machine should satisfy the rate of the line it serves, or more than one machine should be provided.

2. *Rationalization of the number of test positions in the machine with the production rate and the total test process time.* This requires breaking the test time down into bits equal to the desired output cycle. In the example above, if the output needed is a capacitor every 5 seconds then the 30-second charge will have to extend over 6 positions.

3. *Ruggedness.* This must be stressed, even at the expense of space, power consumption, and dollars of first cost. If a project is large enough to justify automatic test facilities, then any down time associated with it will be expensive. A good mechanical design is essential.

4. *Provision of self-stopping and alarm features to serve in the event of certain types of failure.* A limited torque clutch in the main drive will prevent jamming and damage caused by parts getting into the wrong places, or in certain applications overload cutouts will suffice. Gong and lamp alarms are desirable to attract attention. The point is that allowance must be made for mishaps which, without precautions, could result in shutdowns of the equipment.

5. *Provisions of adequate checking for accuracy.* Accessible check points and suitable easy-to-use standards are essential. Checking intervals are determined by experience, but schedules should be laid out to cause as little interference with use as possible. Where practicable there may be means for self-checking in the regular operation of the machine. In this case, periodic checking of the checking devices themselves is necessary.

6. *Incorporation of features in the product and in the handling methods*

that will facilitate feed automatic testing. This requires the cooperation of the product design and product manufacturing interests. It is almost axiomatic that automation in manufacture requires special consideration in product design. Automatic testing imposes the same requirement. A notch or a lug may be needed for proper use of automatic feed devices, or terminals may have to be properly chosen. Again, the method of transport from the previous operation needs to be studied, rationalized, and fully agreed upon. If continuous conveyor transportation can be justified, so much the better. In the consideration of conveyor feed, the need for time flexibility must not be overlooked. It is important that provision be made for easy storage of product whenever the test machine is inoperative, lest a breakdown of this machine shut down the entire line.

7. *Arrangement of the events in the operating cycle in such a way that their sequence is reliably self determined.* This is comparatively straightforward when the programming is done by gear driven cams or other mechanical means. It requires care when switching logic is used. Switching engineers are familiar with the phenomena known as "relay races" and "sneak circuits." These have psychophysical analogies wherever humans and machines work together. The prevention of both the switching errors and their analogs is essential in automatic test set design. Interlocks must be provided against any conceivable mishap.

8. *Enough margin and design flexibility in electrical and mechanical parameters to cope with reasonable variations in product design.* Improvements are constantly being made in telephone apparatus and equipment, and these occasionally result in major redesigns or in entirely new systems. Also the need for adding new features to a historical complex of existing telephone plant causes the generation of an endless variety of special equipments. The product designer needs as much freedom as we can afford. There has to be enough flexibility in the costly automatic test sets to permit adaptation as new designs of product come along.

These considerations are in addition to the fundamental matters of personnel safety and comfort, motion economy, quietness and appearance.

While dealing with general considerations we must recognize one important difference between the product design and the facilities design problems. In product design there is a premium on optimization of parameters, or striving toward perfection. There is generally also opportunity for winning this premium on later tries even though the rush for first production may have denied it to us in the original design. In facilities design there is no such premium and frequently no such opportunity. While careful design is very important, the real premium here is on a

Fig. 1 — Network test position.

device that will do the required job and that can be put in use in time for early production. Once the facility is in use it may be starting on a productive life that will run thirty years or longer. The designer may think of countless ways to improve it or to redesign it completely. If his improvements or redesign can be proved in on a business basis, they may be undertaken. Sometimes they cannot be proved in. The evolution that has taken place in test set designs has been possible mainly because the customers have wanted newer products, or products delivered at a greater rate. Advancement has been attained under a compulsion to take each step quickly and surely. This has represented a real and continuing challenge to the test engineering force.

With these general considerations in mind the author bas cbosen three automatic testing devices of diverse character to discuss in some detail. The associated papers[3, 9] cover additional machines. The machines described illustrate in various ways the principles discussed above.

THE NETWORK TESTING MACHINE AT INDIANAPOLIS[1]

The 425B network[13] is used in the 500 series telephone sets to furnish the transmission link between the handset and the line. Its shop testing requires three tests for transmission, three for capacitance tolerance, three for leakage current, two for ac dielectric strength, one for dc dielectric strength and four for continuity. The rotating turret type test machine (Figs. 1 and 2) performs all these tests, applies a conditioning "burnout" voltage and counts and date stamps the good networks. Rejects from each test position are segregated in roller conveyors. In the rotation of the turret an empty test fixture is presented to the operator every 3¾ seconds moving from left to rigbt. She must load each position, taking networks from the pans at her right; good networks, ejected automatically in a roller chute at the left, are hand loaded into the carriage fixtures of the overhead storage type conveyor, whicb pass within easy reach of the operator's left hand. The pans at the left are used to store good networks when the accessible fixtures of the overhead conveyor are full. The twelve roller conveyors for rejected networks are arranged along the sides of the machine, six on each side.

Tbe turret contains forty test fixtures (Fig. 3 and 4) and the machine forty positions. The turret rotates continuously, causing eleven contact brushes associated with each fixture to pass against fixed commutator segments and a ground ring associated with the test positions. As each fixture advances past one test position a gear connected cam shaft rotates through a complete cycle. Seventeen switches are operated by the cams

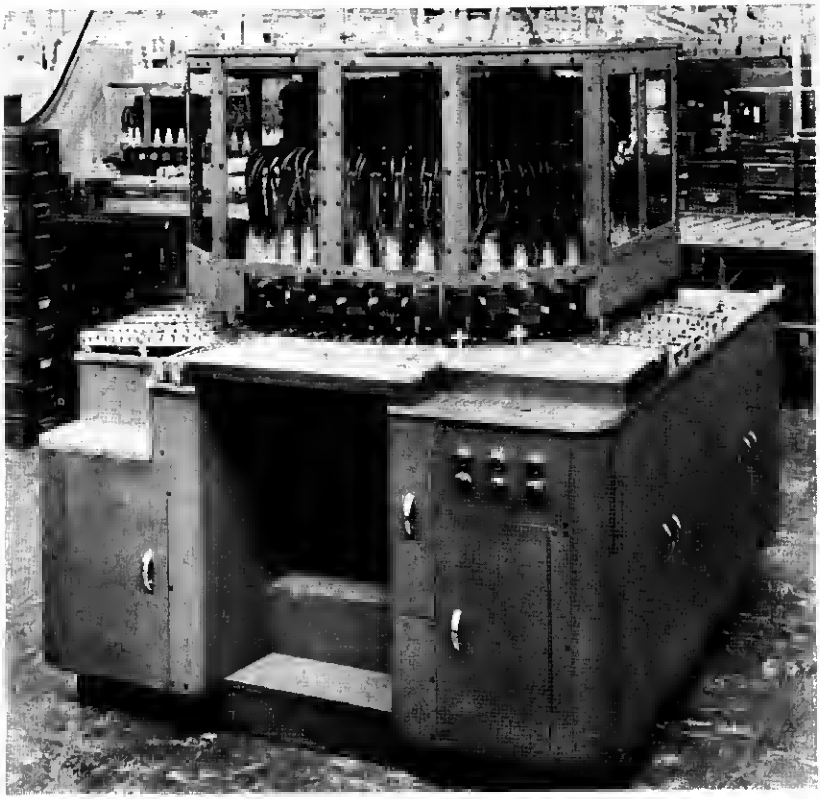


Fig. 2 — The network test machine.

to assure the proper sequence and timing of the conditioning and testing events occurring at the various positions. Table II shows the order of the positions and the approximate timing, with respect to cam rotation. The result of the test at each test position is remembered by a self-locking relay until the fixture comes just opposite the entrance to the corresponding rejection chute. At that instant a cam switch closes and causes rejection if the test result was a failure. Unloading into the rejection chutes is effected by compressed air operated cylinders as explained below.

The clamping movement of each fixture as it leaves the loading area (entering position 7) is driven by a helical spring which lowers the contact fixture over the terminals of the network, bringing spring loaded plungers into contact with the terminals. (See Fig. 3) At a rejection location a plunger rises, driven by an air cylinder under the control of a solenoid operated valve. The rising of the plunger first forces the fixture to

unclamp against the compression of the helical spring, and then operates an ejection arm which drives the network horizontally out of the fixture. The top rollers of several of these ejection arms can be seen in the fixtures at the front of the machine in Fig. 2.

The measuring circuits associated with the various test positions are straightforward. If there is a dielectric failure in one of the breakdown tests at position 8 or 9, the current through a relay coil in series with the

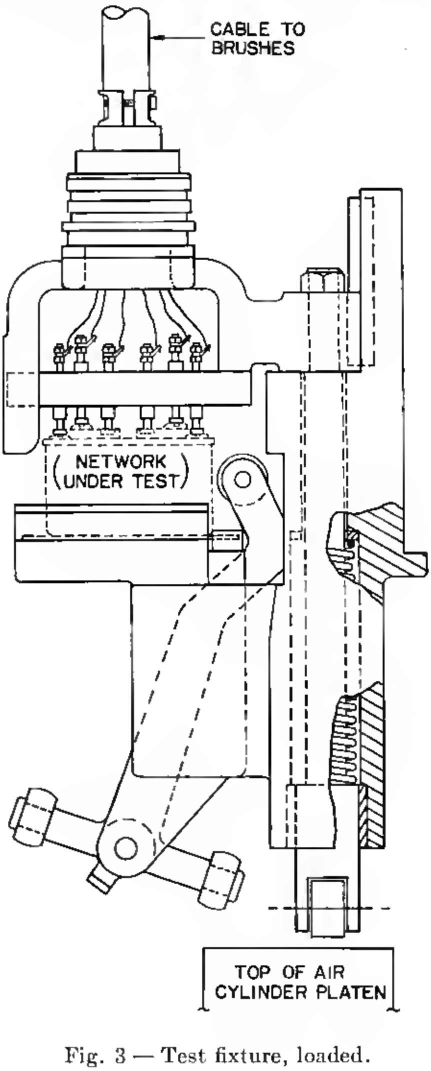


Fig. 3 — Test fixture, loaded.

test exceeds a predetermined value. This causes another relay to lock up and remember the failure until the network reaches the reject location.

In a typical transmission test position (Position 10, 35 or 36) a fixed-voltage, swept-frequency signal, 300 to 3,500 c.p.s., is impressed across two terminals of the network. The three tests are for transmission and short and long line sidetone with suitable terminations connected as in actual use. In each case the signal from two output terminals should be less than or greater than a specified value. This signal is amplified and fed

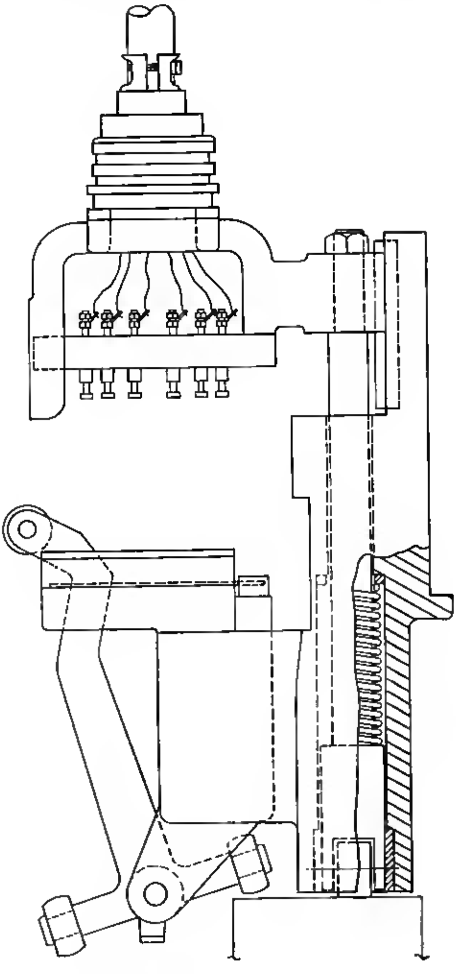


Fig. 4 — Test fixture, unloaded.

to a sensitrol relay, which is mechanically biased in amount and sense to correspond to the limit. If the sensitrol operates it prevents rejection.

In the three capacitance test positions 12, 13, and 14, capacitors in the networks are connected into a 60 c.p.s. comparison bridge. The output signal from the bridge is amplified and rectified, and impressed on a balanced dc amplifier which drives a sensitrol relay. If the bridge is out of balance (that is if the capacitance is greater or less than nominal) current flows in the relay, but always in the same sense. If the current in the relay exceeds an amount corresponding to either capacitance limit, rejection occurs. Determination of which capacitance limit was violated is done manually in a separate analysis of defects. It may be observed also that any rejection at the capacitance positions could have been caused by a loss unbalance of the bridge. If the conductance of the test capacitor were such as to cause this it would so appear in the separate analysis, mentioned above. The effect of any ordinary conductance deviation at 60 c.p.s. is negligible. Quality is protected by the fact that a conductance deviation could not cause an out-of-limit capacitor to be accepted.

Considerable pains are taken at each capacitance test position to prevent damage to the equipment from various kinds of mishaps. The sensitive winding of the sensitrol is short circuited at all times except for about 0.2 second when the actual test is performed. This prevents damage and erroneous rejections that would otherwise be caused by switching

TABLE II — SEQUENCE OF EVENTS IN NETWORK TEST MACHINE

CAM ROTATION →
(TWELFTHS OF A POSITION)

POSITION	PROCESS	0 – 12
1 TO 6	LOAD	
7	BURNOUT	CHARGE (0–6); DISCHG (6–8)
8	AC BKDN.	TEST (0–8)
9	DC BKDN.	TEST (0–8)
10	TRANSMISSION 1	TEST (1–8)
11	DISCHARGE	
12	CAPACITANCE 1	CIRCUIT SETUP (0–3.5); TEST (3.5–4.5); MEMORY (4.5–8)
13	" 2	" ; " ; "
14	" 3	" ; " ; "
15	BURNOUT	CHARGE (0–6); DISCHG (6–8)
16 TO 31 (1 MINUTE)	CHARGE FOR LEAKAGE TEST	CHARGE (0–11)
32	LEAKAGE 1	TEST (1–8)
33	" 2	"
34	" 3	"
35	TRANSMISSION 2	"
36	" 3	"
37	CONTINUITY	TEST 4 CIRCUITS AT ONCE (0–8)
38	UNLOAD	UNLOAD (8–10)
39	RESET	
40	LOAD	
1	"	

EJECTION AT POSITIONS WHERE FAILURES OCCUR (8–9, positions 7–37)

transients from this and other circuits. During the short interval of actual test no other switching takes place in the machine.

A fixture that has no network because of rejection at an earlier test position or because of operator failure to load it, would cause open circuit in one bridge arm on capacitance test. Without intervention this would cause a violent unbalancing of the bridge, overloading of the detector system and possible damage to the sensitrol. Ordinary methods of limiting the overload signal would be only partially effective and would detract from the sensitivity. To forestall this trouble from empty fixtures, each capacitance test position is equipped with a microswitch which is operated by a dog at the bottom end of the ejection arm of any empy fixture (Fig. 3). When the microswitch operates it causes the bridge to be disconnected from the test leads and connected to a capacitor that is just out of limits, several tenths of a second before the removal of the short circuit from the sensitrol. Then when the test is made it results in a rejection.

There is also an interlock circuit which will stop the machine if a failure of the bridge and detector system causes an empty fixture not to show rejection. This serves as a random occasional check on the functioning of the circuit.

The conditioning of the three capacitors for the leakage current tests begins at position 16. Because of charging and absorption currents obscuring the effect of pure leakage, the test for leakage is made to an arbitrary current limit specified at one minute of charge. To insure that good units pass the test, it is desirable to use the whole minute. But if the leakage current reading is taken after more than a minute of charge, quality is jeopardized. Accordingly it is necessary to make sure that the charge is for a minute and no longer on each capacitor. Therefore, at position 16 the first unit is put on charge, at 17 the second, and at 18 the third. Then at position 32 the first unit is tested while the other two remain on charge. At 33 the first unit is discharged, the second tested, and so on.

The leakage test itself is made by measuring the voltage across a large resistor in series with the test capacitor and a dc voltage source. The energy in this signal is small and must be amplified before there is enough to operate a sensitrol. A dc amplifier with high input impedance is used for this purpose. In addition the mechanical bias of the sensitrol is kept small to increase sensitivity, and a carefully controlled dc biasing source is used to insure accuracy and stability.

At position 37 three capacitors and a coil winding are given a final check for continuity. The test of the winding is made by connecting it in series with a relay coil (say No. 1) and battery. If current passes, relay

No. 1 operates. The three capacitors are tested simultaneously by connecting each of them in series with an 8,000 c.p.s. source and detectors. The detectors consist of bridge type rectifiers and relays. If all of these three relays operate, a series connection through their closed contacts causes another relay to operate and lock up. Finally this relay when operated has open contacts in parallel with open contacts on relay No. 1, so that when the reject cam closes it finds an open circuit and rejection does not occur.

The reader may question the necessity for continuity tests on capacitors that have already been tested for capacitance. Perhaps the most convincing answer is that there is an occasional failure on the continuity test. Telephone apparatus is always exposed to more severe conditions in test than it will encounter in ordinary use. The leakage resistance charge and test operations and the transmission tests can on rare occasions cause the metallized connections at the ends of the capacitors to open. As the cost of making the final continuity test is vanishingly small, the additional insurance is economical.

The detail list of checking standards for this machine contains some twenty items. Most of them are modified 425B networks, specially arranged in one way or another to check certain functions of the machine. These are used right in the individual fixtures.

It is interesting to reflect on the labor saving virtues of this machine. The operator in one eight hour shift handles over five tons of networks. She does it easily and without fatigue. The testing would not be even attempted on a manual basis, because over and above multiple handlings, the added human effort of closing fixtures, operating switches and the like could not be tolerated.

In contrast to the multiposition set described above, it is instructive to consider two single position sets of diverse character. They are a relay coil test set and a film scale calibrating set.

THE RELAY COIL TEST SET AT KEARNY[2]

Coil assemblies for the U, Y and UA types of relays[14] are tested for dc resistance, direction of winding and breakdown before assembly into complete relays. Many thousands of the relays are used in any crossbar office. Minimum and maximum tolerance limits are placed on their winding resistances, to control cumulative current requirements and to insure a proper margin of relay operation. Each coil assembly, as presented to the test position, consists of a magnetic core, a solenoidal winding assembly and a terminal assembly. A winding assembly may have one, two or

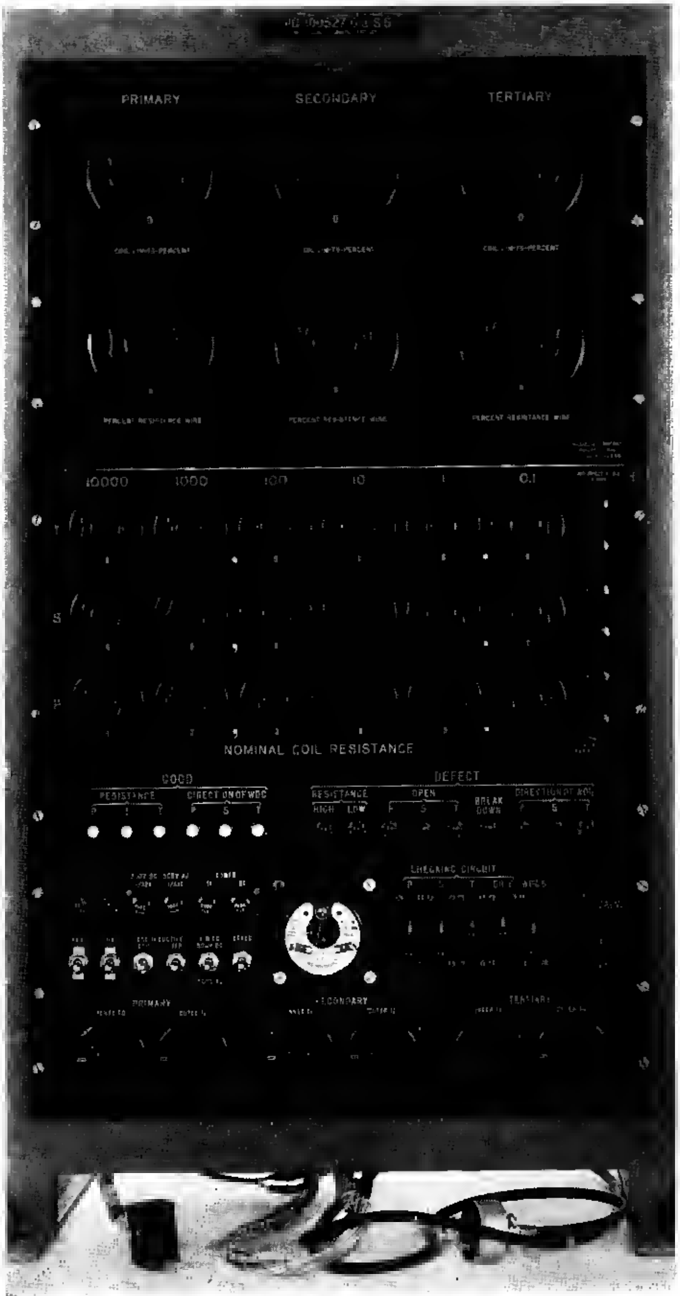


Fig. 5 — Relay coil test set control panel.

three windings (called primary, secondary and tertiary). The primary and secondary are wired to corresponding pairs of terminals on the terminal assembly, while the tertiary leads at this stage are not on terminals and must be connected to the test contact fixture by hand.

Direction of winding is important in the multiwinding coils because of external fields and the fact that the relays are required to respond to currents in more than one winding and the proper direction of flow in each, relative to the other, must be known. In some relays one or two of the windings may be noninductively wound, to serve merely as resistors. Also, many windings are wound part copper and part resistance wire to obtain the desired resistance without unnecessary increase in copper, inductance and response time. In such cases the percentages of copper and resistance wire are known. This is important because of the effect of temperature on the resistivity of copper. Resistance tolerances on the test windings are specified at 68°F, but shop testing is done at any value of room temperature. The effect of the difference on copper is serious enough to cause errors larger than some of the tolerances, and the effect on resistance wire may be neglected. Therefore, it is necessary to have the test set compensated for temperature in such a way as to allow for the proportions of copper and reistance wire.

The coil test set (Fig. 5) tests all windings for resistance and direction of winding and for breakdown to each other and the core. The maximum total test time for three-winding coils is less than 3 seconds under normal conditions. A borderline winding resistance will cause some delay. There are lamps to indicate the type of failure on a rejection. Other lamps indicate satisfaction of the requirements. At the completion of test on a good coil an "OK" lamp lights on the test fixture, so that the operator need look at the set itself only when there is a rejection.

Requirements data are stored in the set before a given code of coil is tested. The codes come to the set in batches, so that one setup will serve for a large number of coils. Three six-decade resistance standards are set to the nominal values for the respective windings. If there are fewer than three windings, a key is operated to disable bridges and furnish substitute continuity paths. The percentage tolerances for the windings are set on selector switches: ± 1, 2, 5, 10 and 15 per cent tolerances are available. Also, the known percentages of resistance wire in the windings are set on selector switches in steps of 5 per cent from 0 to 100. Keys are operated to warn the set of noninductive windings and bypass the direction of winding circuits as needed.

Once a coil is placed and connected in the test fixture and the fixture closed by operation of a pedal, the test is automatic up to the point where

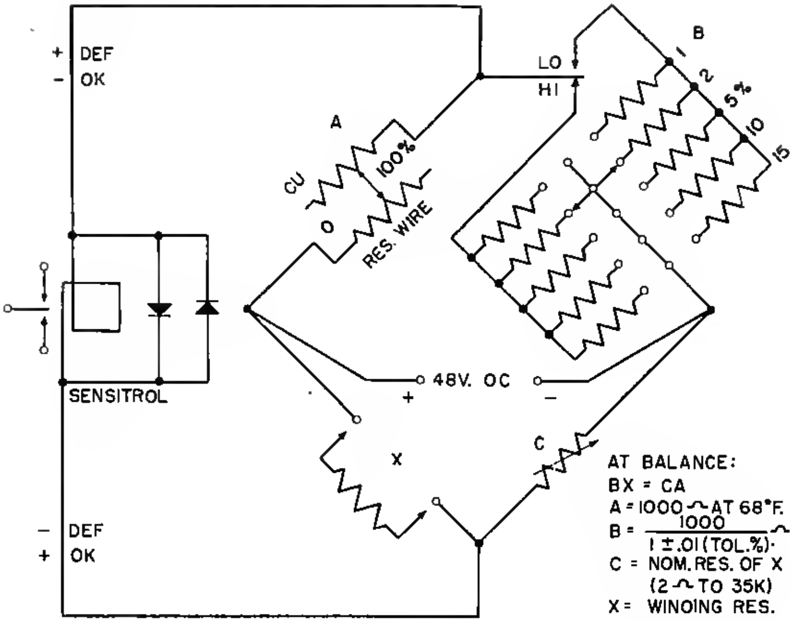
the operator must make disposition. The sequence of events within the set is controlled by a switching circuit containing thirty telephone relays, a sensitrol relay and two electron tubes. The sensitrol is used in succession to detect the existence and sense of unbalance of six dc bridge circuits (high and low limit for each of three windings). The operation sequence for primary windings is shown in Table III.

Fig. 6(a), shows schematically a typical bridge arrangement for testing a winding at one tolerance limit. A and B correspond to the ratio arms of an ordinary Wheatstone bridge, and are nominally 1,000 ohms each. The temperature compensation referred to above is obtained by including the same resistance percentage (within 2.5 per cent) of copper in the A arm of the bridge as there is known to be in the winding. Inspection of the bridge balance equation in Fig. 6(a) will show that an error in X could be compensated by a proportional error in either A or C. A is chosen as the compensating arm because of its simplicity. It has available twenty resistors of copper and twenty of low temperature coefficient resistance wire. Each resistor is 50 ohms, measured at 68°F. The selector switch is arranged so that the arm always has twenty resistors, the indicated percentage being resistance wire.

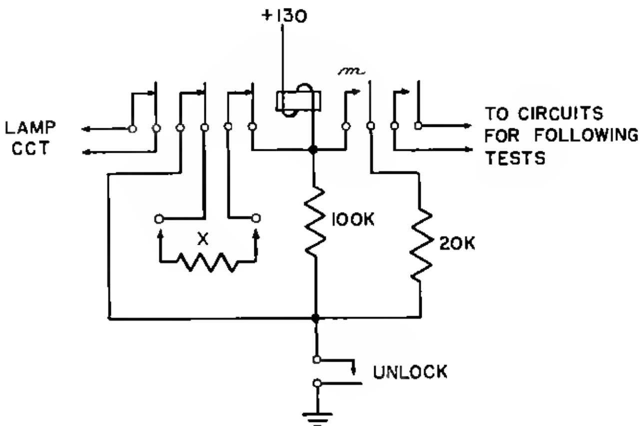
For proper compensation it is necessary that the A arm be as near ambient temperature and the temperature of the coils as possible. The di-

Table III — Sequence of Events in Test of Primary Winding for High Limit Resistance

"OK" LAMP	STEP	DEFECT LAMP
	POWER SWITCH CLOSED	
	SENSITROL RESETS AND HOLDS	
	OPERATOR CLOSES FIXTURE	
	FIXTURE START SWITCH CLOSES	
	CONTINUITY TEST – ALL WINDINGS	"P OPEN" ETC.
	"HIGH" B ARM CONNECTED TO PRI. BRIDGE	
	SENSITROL RESET RELEASED	
	SENSITROL OPERATES	"HIGH"
	"LOW" B ARM CONNECTED TO PRI. BRIDGE	
	BREAKDOWN TEST ON PRIMARY	"BREAKDOWN"
	SENSITROL RESETS AND HOLDS	
	SENSITROL RESET RELEASED	
"P RES. GOOD"	SENSITROL OPERATES	"LOW"
	DIRECTION OF WINDING DETECTOR ENABLED	
	D.C. POWER DISCONNECTED FROM PRIMARY BRIDGE	
	INDUCED VOLTAGE IN PICKUP COIL	"P DIR. OF WDG. DEFECT"
("OK")	SENSITROL RESETS AND HOLDS	
	"HIGH" B ARM CONNECTED TO SEC. BRIDGE	
	(SECONDARY TEST PROCEEDS; SIMILAR TO PRIMARY)	
	(FOR SINGLE-WINDING COIL, LAMP ON FIXTURE LIGHTS)	



(A)



(B)

Fig. 6 — Circuits used in Relay Coil Test Set. (a), resistance bridge, simplified schematic; (b) continuity, simplified schematic.

vision into twenty resistors helps in this by maintaining high effectiveness of dissipation. In addition, the automatic switching circuits are arranged to keep the duty cycle of current in the bridge arms low.

The B arm of the hridge is selected hy the setting of the percentage tolerance switch. Each resistor is used alone and consists of low temperature coefficient resistance wire as in standard bridge practise. The value of each resistor in ohms is 1,000 divided hy one plus or minus the corresponding tolerance fraction. Thus, for ± 1 per cent tolerances the resistors are 1,000/1.01 (=990.0) and 1,000/0.99 (=1010.1), respectively. One setting of the switch indicates zero tolerance and is equipped with 1,000-ohm resistors to permit easy checking of the C arm precision.

The six-decade standard resistor in the C arm, which is set to the nominal value of the test winding, is of a high quality commercial type with a range of 0 to 40,000 ohms in steps of 0.1 ohm. Because the C and X arms may contain values as low as 2 ohms, no relay contacts are used in them. Relay switching is donc in the A and B arms where the resistances arc always of the order of 1,000 ohms and small variations in contact resistance are negligible. The more stable wiping contacts of selector switches do appear in the X arm. These switches permit any contact in the test fixture to be connected to any bridge terminal, to enhance flexihility.

A continuity test on all windings, before resistance test, is desirahle for two reasons. The effect on the sensitrol of the severe hridge unbalance caused hy an open winding would he life-shortening and is to he avoided if possible. Also, the result of the resistance test would only show high resistance, and separate analysis would be needed to reveal that a winding was open. The continuity test circuit in Fig. 6(b) was devised to prove continuity for windings having resistance values as high as 35,000 ohms. A relay (UA-104) was chosen which is sensitive enough to close a pair of "preliminary make" contacts (m) on 0.005 ampere, and which provides the number of other contacts needed to satisfy circuit requirements. When the test winding is connected at X, the currents through it and the 100,000 ohms comhine to equal 0.005 ampere or more. This closes m, connecting the 20,000-ohm resistor in parallel with the 100,000 ohms, thus locking the relay and assuring that all the other contacts operate. In the act of proving continuity, the relay disconnects itself from the test winding and remains locked. The make contacts shown at the right end of the relay symbol are in series with similar contacts on the continuity relays for the other two test windings, and when all are closed they pass operating current to a relay which initiates the first resistance test (for primary high limit).

In the direction of winding circuit, Fig. 7(a), it is necessary to have a negative pulse from the pickup coil, in the test fixture, cause the 313CA

gas tube to fire and the relay to operate. The circuit is designed to handle a wide range of pulse amplitudes. The VR tube limits negative pulses to 90 volts to protect the 6AK5. The varistor dissipates positive pulses and prevents any false acceptance that might be caused hy damped oscillations following a positive pulsc. The 6AK5 furnishes the needed sensitivity for small pulses.

Occasionally a winding will havc a value of resistance just equal to

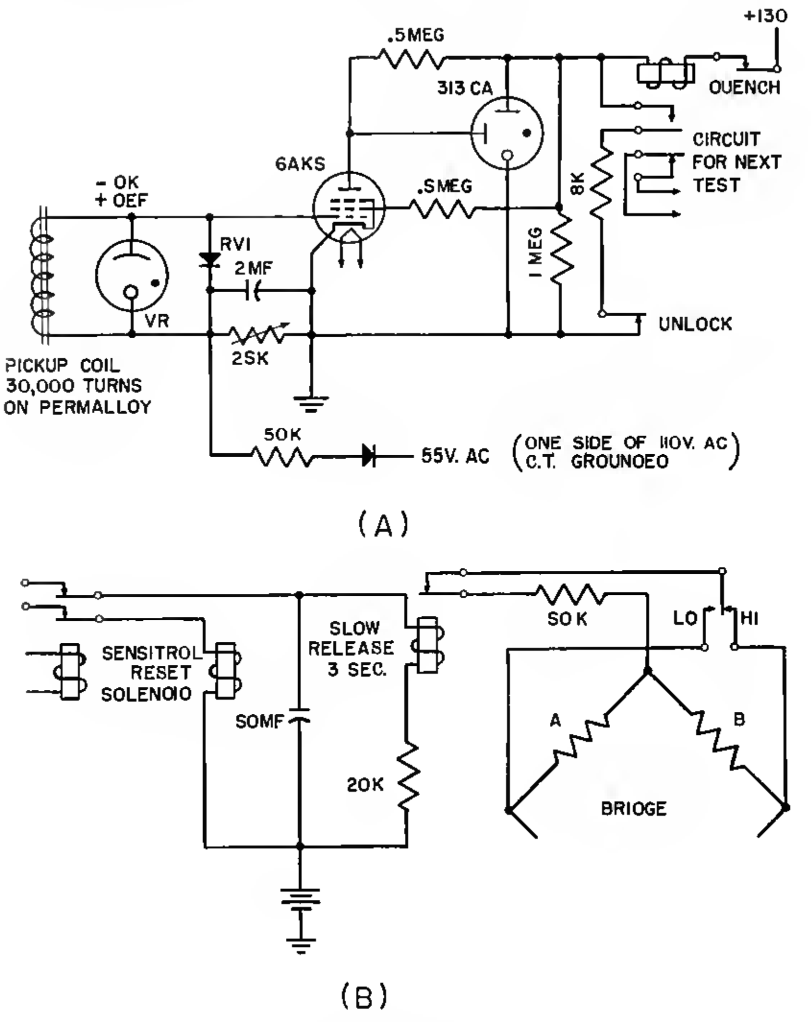


Fig. 7 — Circuits used in relay coil test set. (a), direction of winding, simplified schematic; (b) anti-stall, simplified schematic.

its upper or lower tolerance limit. On the corresponding resistance test, the sensitrol will balance and uot operate either way. Without an anti-stall device the test cycle would then be stalled until the balance failed. Current flowing through the A arm would eventually heat it up and vitiate the temperature compensation feature. The anti-stall circuit in Fig. 7(b) is essentially a slow release device to which external energy is interrupted at the same time as the sensitrol reset is released. Energy stored in the 50-mf capacitor prevents release of the relay for about 3 seconds, long after the bridge test is ordinarily finished. If at release the bridge is still balaueed, a 50,000-ohm resistor is thrown in parallel with that ratio arm which will make the sensitrol accept the test winding.

A prominent and hitherto valuable feature of this test set is its adaptability to a large variety of coil assemblies. Some hundreds of distinet designs of product are presently accommodated. In the Kearny relay coil shop there are four sets of the design described here and four sets of earlier designs. It is possible that future development, if justifiable, will be directed toward greater automaticity for some of the simpler and more numerous product eodes, witb less empbasis on universal appliea-tion.

THE CALIBRATING MACHINE FOR 56-A OSCILLATOR FILM SCALES[5]

Photographic films are used for the frequency scales of some oscillators to afford scale length and enhance readability. There have been several successive designs of film scale calibrators built and put in use at tbe Bell Telephone Laboratories and at Kearny. Some have been described in the literature.[16, 17, 18] One very early design is still iu use on production at the Marion Shops in Jersey City. In its use, a calibrating run requires about an hour, aud the possibility of frequency drift due to temperature variations makes the use of an air conditioned room essential. All of tbose used at Western, prior to the one described here, depended for accuracy on the film scale of a standard prototype of the oscillator to be calibrated. Using a frequency controlled servo linkage, the scale of the standard was reproduced photographically on the film of the product. Some of the prior art appears in the design of the new maehine. In order to describe the principle clearly, it seems necessary to discuss some features which were previously covered, but which now are used in new ways.

The 56A is a heterodyne oscillator designed for use in the field testing of L3 installations.[15] It has a usable range of 50 kc to 10 mc. One component oscillator is fixed at or near 90 mc and the other may be varied between 80 and 90 mc by means of a tunable cavity. The calibrated portion of the 35-mm film scale geared to the cavity tuner is about 17

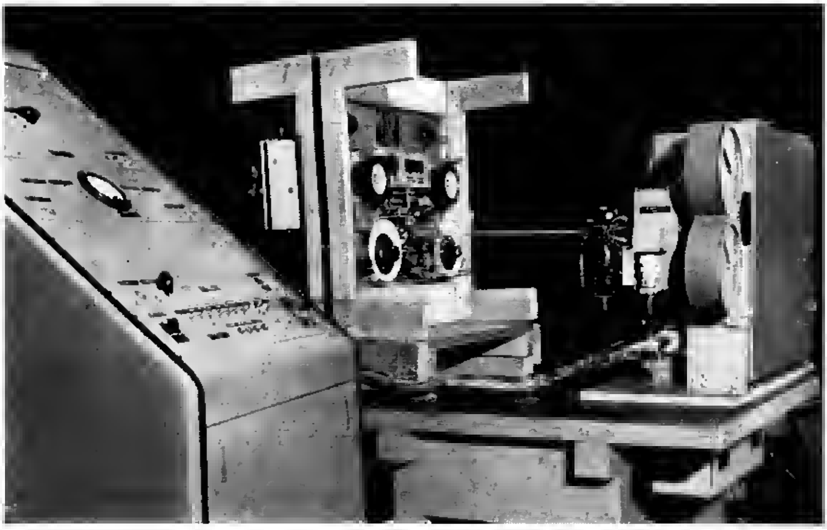


Fig. 8 — Film scale calibrator.

feet long. It has sprocket holes and is moved by a standard movie sprocket. The required precision of each calibration mark is ±2 kc. Two resonant devices are included in the circuit to permit checking and adjusting two widely separated points on the scale, 100 kc and 7,266 kc. Considering the output frequency as a function of scale setting, one of the two adjustments controls the lateral displacement of the curve and the other its average slope. By design the curve approaches linearity but not closely enough to permit less than a unique calibration for each oscillator manufactured.

Fig. 8 shows the machine which performs the calibration, with an oscillator connected, and the control cabinet. The oscillator is shown in its shipping frame. An unexposed photographic film to be calibrated is mounted in a camera so that it can be driven by a sprocket. The sprocket is connected by gears to a drive motor which also drives the take-up reel and, through a flexible shaft, the cavity tuner and sprocket in the oscillator itself. The gear arrangement is such that the peripheral speeds of the two sprockets are the same.

A positive master film is provided which has a scale similar to the one to be made for the product except that it is very precisely linear. A portion of the master is shown in Fig. 9(b). The master film passes over a sprocket which is driven by a servo motor. A lamp illuminates and shines through that portion of the master which is in front of an aperture at

any instant. An optical system, Fig. 9(a), produces on the unexposed film an image of the illuminated portion of the master. As the oscillator, its film, and the master advance, the markings on the master can be reproduced on the new film.

The problem in control is to cause each mark on the master film to pass the slit just as the oscillator goes thru the corresponding value of frequency. To do this we drive the oscillator and its scale together at a constant linear speed. The oscillator frequency increases steadily but not at a constant rate. Its rate of increase varies according to the law of its particular cavity. So our problem reduces to causing the master film to move according to that same law.

The method is to time the passage of known points in the oscillator frequency spectrum, and then to pace the movement of the master film to maintain precise correspondence. The pacing is done by detecting small differences in times of arrival at corresponding points and correcting the speed of the master film to keep successive differences small. Fig. 10 is a block schematic of the automatic control system. The varying oscillator output passes through multiples of 10 kc at a rate near five multiples per second. When it is compared in a balanced modulator with

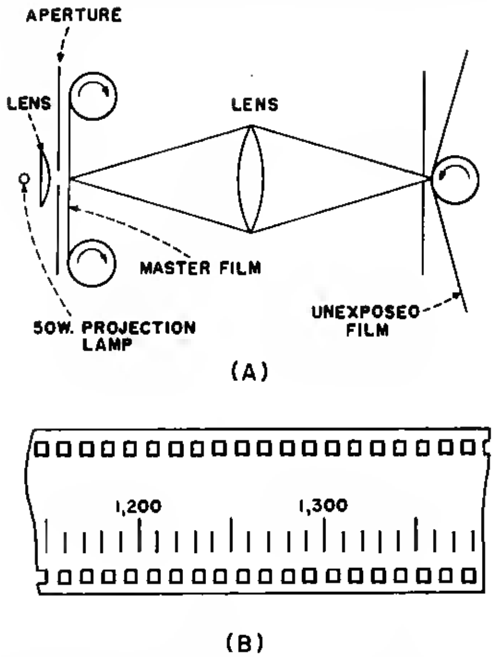


Fig. 9 — Film scale calibrator. (a), optical system schematic; (b) section of master film.

the fixed harmonics of a standard 10-kc signal, the first order difference frequency in the modulator output varies back and forth between 0 and 5 kc. It passes through the 2500 c.p.s. point twice per period of variation, or twice per 10-kc interval of the oscillator frequency.

The output of the modulator is sent through a narrow band amplifier which peaks at 2500 c.p.s. A burst of signal, therefore, leaves this amplifier twice per 10-kc interval. The bursts are further amplified and rectified and become pulses which time the progress of the oscillator through its spectrum. The pulses are impressed across the winding of a high speed relay, causing its contacts to close momentarily twice per 10-kc interval. During the instant when the contacts are closed they connect a particular value from a sawtooth voltage wave to a 0.1-mf capacitor.

The voltage of the capacitor biases the grid of a cathode follower tube, and the output voltage from this tube is fed to a servo system and controls the speed of its motor. Thus the motor runs at a speed determined by the voltage of the sawtooth at the instant when the relay contacts close. As the sawtooth itself is timed by the rotation of the servo motor, its voltage-time relationship is the device for pacing the master film. The sawtooth wave originates in the alternate shorting and charging of a 1-mf capacitor. Each tooth begins when a pair of shorting contacts is closed momentarily by a cam geared to the servo motor. After a discharge, the voltage on the 1-mf capacitor increases negatively as a practically linear function of time, with charging current flowing through a one megohm resistor. Thus the value of voltage transmitted to the 0.1-mf capacitor at the instant of closure of the relay contacts depends on the time elapsed since the most recent shorting of the 1-mf capacitor. Twenty volts at the input to the servo system corresponds to midvoltage of the sawtooth and to 3,600 rpm of the motor, which is the same as the constant speed of the motor driving the oscillator and undeveloped film.

If the characteristic of the oscillator causes a given 2,500-cycle point to occur early, the contacts of the relay will close at a higher positive voltage point on the corresponding sawtooth. The servo motor will start to speed up to make subsequent sawteeth start earlier than they otherwise would have. The motor will slow down if the 2,500-cycle points fall later and lower on the teeth.

Several design features in the system are of interest. The servo system was supplied by Industrial Control Company (SL-1035). It has a tachometer feedback in inverse sense to enhance system stability. The cam used to operate the shorting contactor and start the sawtooth is a small permanent magnet mounted on a wheel. The moving field causes the contactor to operate very briefly as the magnet swings past. The contactor itself is a Western Electric 222-A mercury switch, which has a

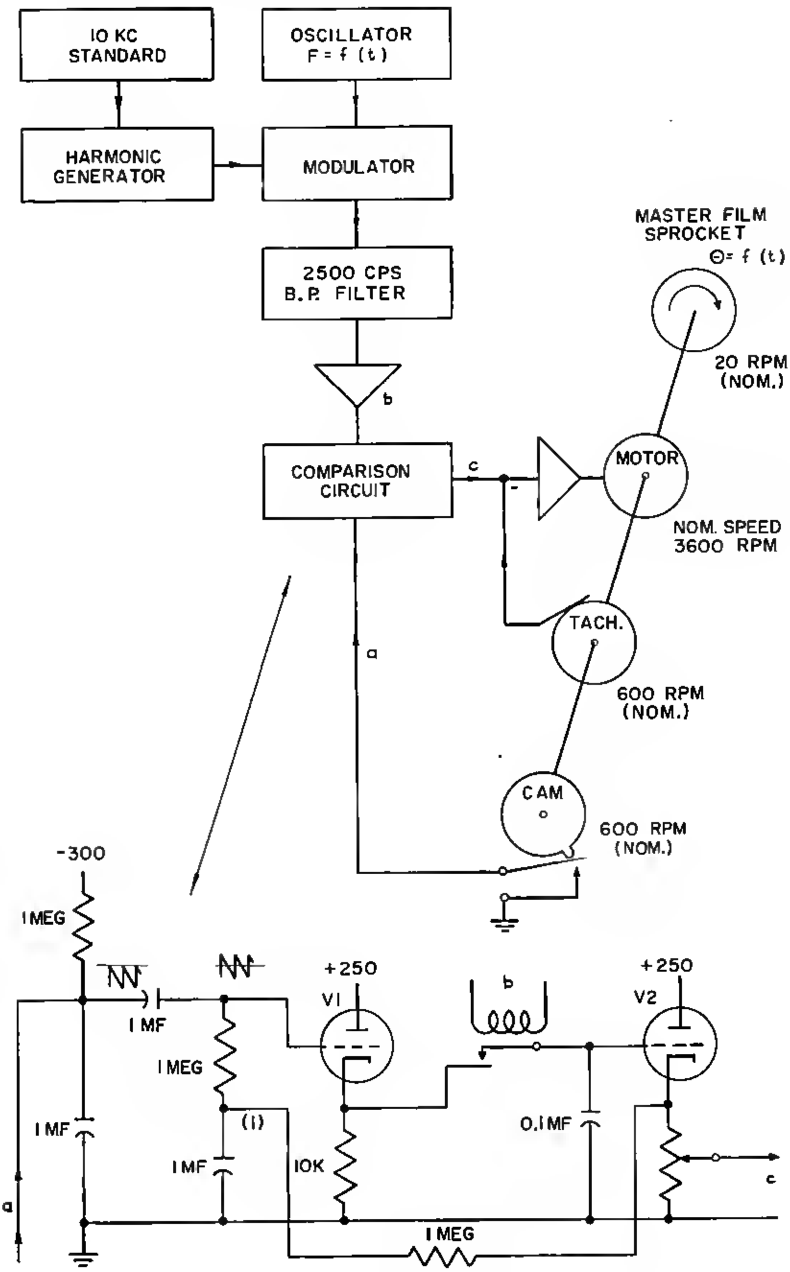


Fig. 10 — Block diagram of film scale calibrator with schematic of comparison circuit.

hydrogen atmosphere, high speed capabibty and high current capacity. The magnetic arrangement reduces shock torque loads on the servo motor, which might result from mechanical operation. The high speed relay which operates at the 2,500-cycle points is a Western Electric 275-B, chosen because of the speed required (about 10 operations per second).

The time comparison circuit has a small amount of long time constant positive feedback (shown at 1 in Fig. 10) to raise or lower the midvoltage of the sawtooth wave in cases of extreme correction and prevent the control póint from slipping one or more teeth. In effect this supplies extra acceleration to the master film when needed.

There is also incorporated in the design an arrangement which permits an important variation in the method of use. A magnetic tape is driven by a sprocket which is geared to the main drive motor and moves with the oscillator drive. The magnetic head for recording on the tape receives its signal in the form of 2,500 c.p.s. hursts through an amplifier. These are the same bursts that time the progress of the oscillator through its spectrum. Thus it is possible to separate the function of calibration from that of printing the film scale. The calihration data on the oscillator is stored on the tape and may be checked for absence of abrupt departures from linearity before it is used to drive the servo and master film in an actual printing run. This eliminates some wastage of raw film. Also a recording (or calibrating) run is made without the servo linkage and can be made at twice the speed of a printing run. A 56A oscillator can be driven through its spectrum, 50 to 10,000 kc, in 100 seconds, allowing very little opportunity for temperature effects to change tbe check points. In fact no particular effort need be made to control the temperature beyond an ordinary warm up interval.

The control portion of the machine contains various circuits for convenience in setting up and starting the runs. For example one relay circuit under the control of a start button brings a fixed dc voltage into the servo loop, and automatically disconnects after a period long enough for the motor to reach approximately the right speed. A gear shift lever permits changing the ratios between the speeds for the recording run and the printing run.

It is doubtful that a calibration of the 56A oscillator could be performed by manual means. It has been estimated that even if possible, such a task would require more than a week of the most painstaking effort, under very carefully controlled conditions. By comparison, the calibrator requires one minute forty seconds to obtain the data, and three minutes twenty seconds to reproduce it. Development and checking of the exposed film takes about a day. Accuracy of the scales has always been well within the ±2-kc limit.

CONCLUSION

In this and the accompanying articles we have given a partial picture of the facilities for automatic testing in the Western Electric Company. At this writing several new machines are under development, and modifications are in progress extending the application of some of the present machines. There is a continuing search for new fields in which to apply these techniques. A staff portion of the manufacturing engineering force now devotes its full attention to automation techniques in general, keeps abreast of the field, bulletinizes important additions to the literature, lends assistance in the solution of problems, and develops specific applications. It is likely that the near future will see important extensions in the use of automatic test equipment.

ACKNOWLEOGMENTS

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